Energy-efficient design and operation of fume cupboards

- The running costs of a standard individual fume cupboard can amount to £750 per year
- Most of the energy used is needed to condition make-up air
- Energy costs can often be reduced by 75% through good design and simple management steps

GOOD PRACTICE GUIDE 320

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

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CONTENTS

OVERVIEW

BACKGROUND

Fume cupboards are used extensively both in industrial organisations and in hospitals, schools and universities. They are used not just for performing designated experiments involving substances that may give off harmful vapours, but also for testing and weighing potentially toxic substances or for storage (either in the fume cupboard itself or in a cupboard beneath it).

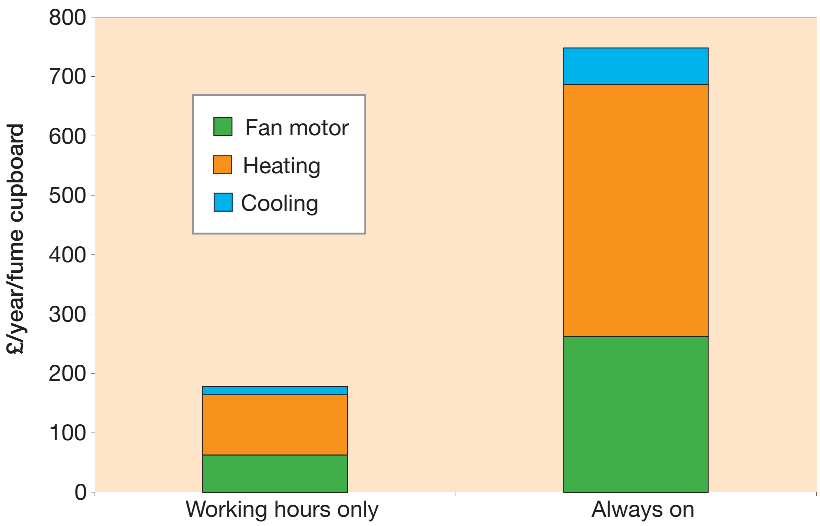
A fume cupboard is a partially enclosed space for undertaking experimental work, which is maintained under negative pressure by an extraction system that removes harmful gases. The extraction system maintains airflow into and through the fume cupboard from the room in which it is located.

The amount of energy that fume cupboards use is often underestimated, as the energy needed to heat or cool make-up air is commonly overlooked by fume cupboard users. The chart below shows how the costs are proportioned for a fume cupboard that is left running continuously and one that is switched off outside working hours.

These costs can be reduced significantly by:

- correctly specifying fume cupboard systems at the design stage; and
- taking simple measures to ensure that they are managed properly.

Fume cupboard running costs



The primary consideration in fume cupboard design and specification should always be for safe operation of the cupboard. Hence any recommendations made by this Guide include references to Health and Safety legislation where appropriate.

ABOUT THIS GUIDE

The Guide will be of interest to:

- Laboratory managers responsible for the day-to-day management of fume cupboards
- Facilities managers of buildings with fume cupboards
- Engineers responsible for the design and specification of systems
- Users of fume cupboards.

The topics covered include:

- Energy consumed by fume cupboards in use
- Energy efficiency features that are available for fume cupboards and the situations in which these are appropriate
- Energy-efficient operation, including tips for end users on energy-efficient use of fume cupboards, and advice for laboratory managers on day-to-day management.

A glossary of terms can be found on page 14.

Energy used by fume cupboards

The amount of energy used by fume cupboards is much greater than just the fan power, which is a relatively small component of a fume cupboard's overall energy use.

Energy is also needed to heat or cool air which replaces the conditioned air extracted by the cupboard.

Employing good practice techniques can reduce extraction rates and therefore save on the energy required to condition make-up air.

FUME CUPBOARD USE

Fume cupboards are used for a variety of applications. It is important that safety is the primary consideration in any situation that requires the use of a fume cupboard and that regulations governing their safe operation are adhered to.

There are three main areas in which fume cupboards are used. These are for teaching, for research, and in quality control situations.

TEACHING

In schools and universities where fume cupboards are used for teaching purposes, the hours of use will be dictated by the timetable and the syllabus requirements.

Recommendations for provision of fume extraction systems in schools are set out in detail in Building Bulletin 88 (a revision of Design Note 29), available from the DfES.

The performance specifications for fume cupboards that are to be used in schools are lower than for those intended for use in universities, industry or research institutions. This reflects the fact that less hazardous materials are used in schools.

RESEARCH

Research laboratories can be found in universities, industry and dedicated research institutions.

The nature of research work often means that experimental work is carried out over long periods, which may require fume cupboards to be left running outside normal working hours.

QUALITY CONTROL

Fume cupboards are also widely used in industrial situations where companies carry out quality control checks on their products.

This again can lead to extended usage to match the production operating hours.

Details of COSHH Regulations and recommendations made by British Standard BS7258 that affect fume cupboard use are given on page 14.

Copies of COSHH Regulations can be obtained in full from the Stationery Office, whilst recommendations for the use of fume cupboards contained within BS7258 are available from the British Standards Institution. Contact details for these can be found on page 15.

ENERGY-EFFICIENT DESIGN OF FUME EXTRACTION SYSTEMS

The energy performance of a fume cupboard installation depends not only on the design of the cupboard but also on the design of the make-up air supply and extract systems. All three elements of the system need to be integrated and should be specified together, taking account of appropriate legislation and regulations.

MAKE-UP AIR SUPPLY SYSTEM

The make-up air replaces that being extracted from the lab by the fume cupboard when it is in operation. This is normally air supplied mechanically at a fixed rate, or the volume of make-up air can be regulated by variable speed fan controls and/or localised damper systems to balance the amount extracted by fume extraction systems.

It should be borne in mind that infiltration systems where air is drawn into the lab through grilles, diffusers, doors and windows can cause draughts that can seriously compromise the containment of fume cupboards. Air supplied in this way will also not be filtered or temperature controlled.

The capacity of the supply fan should be specified at the building design stage – it may be worth considering whether an existing fan could be downsized, although allowances for future use should be made.

A variable speed drive installed on the fan can modulate the volume of air supplied to the lab to match the volume of air extracted.

Ensuring that the make-up air supply system is fitted with efficient controls can also be important in reducing energy costs. For example, the make-up air supply system should function only when fume cupboards are in operation. This can be achieved through the installation of Variable Air Volume (VAV) systems on to the make-up air supply controls.

EXTRACT SYSTEM

The fume extract system comprises of the connection to the fume cupboard(s), ductwork, the fan and discharge outlet.

The system should be designed to operate at the face velocities stipulated by the manufacturer to achieve adequate containment of fumes in line with BS 7258.

The design of the ductwork and the fan should satisfy the maximum air flow rate for all fume cupboards served by the system.

All fume cupboards in a lab can be served by one extract fan, but this is energy efficient only if a VAV system is fitted to the fume cupboards. When using standard fume cupboards it is not possible to switch off individual cupboards or reduce the extract fan volume.

Sizing the fans according to the number of fume cupboards that are likely to be in use at any one time, rather than the total number of fume cupboards installed, can save capital costs, as well as reducing energy consumption.

This is known as applying a diversity factor to the system; it does, however, require a VAV system to be installed on to the fume extraction system. The level of diversity will also depend on the type of work that goes on in the laboratory – for example, if all the fume cupboards are required to be working with sashes open at all times, as is often the case in university teaching labs, no diversity factor can be applied.

ENERGY-EFFICIENT DESIGN OF FUME EXTRACTION SYSTEMS

During normal operation, a single 1500 mm wide fume cupboard will extract approximately 1200 m^3 of air per hour. This means that in a lab 4 m square, the entire volume of air in the lab would be replaced 30 times in each hour.

The discharge velocity from the extract fan stack is important, since contaminated fumes must be thrown clear of the roof to avoid them being pulled back into the building via the make-up air system. BS 7258 recommends a minimum discharge velocity of 7m/second.

Backward curved centrifugal fans are generally more efficient, generate less noise, and operate over a wide range of air flows without instability. Fans should be selected so that their performance in normal use is near the point of maximum efficiency.

Obviously, any systems and controls installed to modulate the output of the extract fan will need to be reflected in the operation of the make-up air supply fan. Any method of reducing the extract volume from the fume cupboards linked to a similar reduction in make-up air volume will result in a saving in energy costs.

An important safety consideration for fume cupboard selection is the 'face velocity'. The face of a fume cupboard is the open area that allows users to access the equipment and chemicals within the fume cupboard when the sash is raised.

When the fume cupboard is being used, air flows through the 'face' as it is extracted. The speed of this air is known as the 'face velocity', and a minimum face velocity can be determined for various laboratory activities.

The fume cupboard found in most laboratories is the conventional face and bypass cupboard. The sash is approximately half of the height of the fume cupboard, so that when the fume cupboard is in use and the sash is raised, the flow of air from the laboratory is through the open 'face' of the fume cupboard. When the sash is lowered a bypass grille above the face of the fume cupboard is exposed, and air from the laboratory is extracted via this grille. The system is designed to avoid increases in air velocity across the face of the fume cupboard when the sash is lowered.

Consequently, a constant volume of air is drawn through the cupboard, irrespective of the position of the sash, which is not energy efficient. Without the installation of additional features, therefore, the only way to reduce energy costs with this type of cupboard is to switch off the cupboard when it is not in use.

Installations with several fume cupboards on a single extract system are common, due to the reduced outlay for, and subsequent maintenance of, ductwork. However, this type of installation will not allow individual cupboards to be switched off when not in use, and so is not energy efficient.

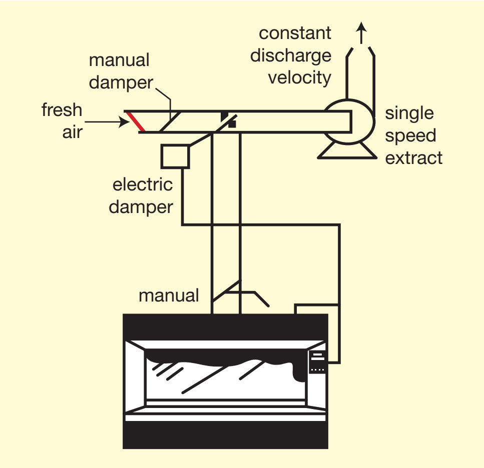
ENERGY-EFFICIENCY FEATURES

The simplest way to reduce extract volume, and therefore reduce energy costs, is to use a two-speed system – where the extract fan is linked to a switch operated by the fume cupboard sash. As the sash is lowered to a half-open position, the fan is switched to a slower speed (usually 50%). A minimum face velocity is maintained, ensuring that containment is not affected.

This feature is possible only for installations with an individual fan system. It is important to ensure that the system can maintain minimum discharge velocity from the exhaust stack.

Installation of a **variable speed drive** on the extract fan achieves constant face velocity as the sash is closed by changing the fan speed and therefore the extract volume. When the sash is moved from fully closed to fully open, the control system must ensure that the fan changes speed quickly enough to prevent fumes leaking from the cupboard. It is also important to ensure that minimum discharge velocity can be maintained.

Variable air volume (VAV) systems are available that control airflow in the extract duct from each cupboard – flow is controlled by variable speed motors or dampers located in the ductwork. A pressure sensor controls the damper position or fan speed. As the sash is closed, the airflow is adjusted so that minimum face velocity is maintained whilst the extract volume is reduced.



Fresh air bleed system

These systems allow many cupboards to be connected to one extract system – each cupboard can be controlled individually (unlike a constant air volume system with a central fan), and both energy and capital costs are reduced. VAV installations will also allow a diversity factor to be applied to the extract and make-up air systems.

The more fume cupboards there are, the more cost effective this type of installation is; however, there will be extra costs associated with the maintenance of the electronic controls required by these systems. If the make-up air supply system is constant air volume, this will also need to be replaced.

The chemical processes that will be performed in any cupboards connected to the same system, such as a shared extraction system, may allow chemicals to mix and react. Care needs to be taken in specifying such a system.

VAV systems can incorporate a **fresh air bleed system**, whereby a damper located in a branch duct can be opened to allow outside air to be pulled into the main extraction duct. This supplements the air being extracted from the lab with the result that, overall, less conditioned air is extracted. This is applicable for systems with a single speed fan as well as variable speed.

An **automatic sash closing mechanism** can be used in conjunction with a VAV system to close the sash when the operator is not working at the cupboard.

In some situations it maybe possible to install a **plate heat exchanger** – simply an array which is pre-heated by exhaust air, and which then heats incoming air. However, exhaust air can be contaminated with chemicals that can corrode the heat exchange plate, so this has limited use.

Ductless fume cupboards that re-circulate exhaust air to the lab are available. The air is passed through filters which absorb particular chemicals – these types of cupboards are suitable only for operations where specific chemicals are used in known quantities.

ENERGY EFFICIENCY FEATURES

Where all the fume cupboards are in use all the time, having a central fan system saves energy and maintenance costs.

CIBSE Guide B2 states that, generally, good containment can be achieved at face velocities of 0.5m/s, although it may also be achieved at lower face velocities depending on the design of the fume cupboard. Whilst a face velocity of 0.5m/s is appropriate for most purposes, the actual requirement will depend on the application.

Naturally, when specifying these installations, it is important to consider factors or circumstances, particular to your lab, which could have an effect on the performance of a fume extraction system, such as cross-draughts and air currents.

Consideration should also be given to the initial capital costs as well as potential savings, as both of these can vary depending on factors such as age, location or use of individual fume cupboards.

The table below summarises the features covered in this section, and the situations in which they might most appropriately be used.

Feature	Use
Re-circulatory filtration/ Ductless fume cupboards	There is limited use for ductless fume cupboards, as the selection of filters will depend on what chemicals are being used in the lab and in what quantities.
Two-speed system	This is possible only where each fume cupboard is connected to an individual fan system.
Variable-speed extract fan	Used for single fume cupboards where the speed of the extract fan varies according to sash height. Can be used in conjunction with features like automatic sash closing sensors, fresh air bleed.
Central fan system	Can be used for conventional fume cupboards at constant volume or VAV fume cupboard installation, and allows the incorporation of features such as fresh air bleed.
Variable air volume	Used for single speed and variable speed extract fans, on individual and central fan systems, and in conjunction with fresh air bleed systems and automatic sash-closing mechanisms. Requires VAV installation for make-up air and 'intelligent' controls.
Heat recovery system	Limited use due to possible corrosion problem and relatively low-temperature extract air. Can be retro-fitted on to existing systems.
Fresh air bleed system	This system is good for use in conjunction with single-speed fans; it can also be used where several cupboards share a fan, in conjunction with a VAV system.
Automatic sash closing mechanism	Used in conjunction with a VAV control system to increase the energy savings.
Diversity factor	Needs to be used in conjunction with a VAV system. Application is limited by the number of cupboards that will be in use at any one time; diversity cannot be applied where all fume cupboards work with sashes open at all times. Other features like fresh air bleed can be incorporated.

ENERGY-EFFICIENT OPERATION

It is important for end-users to think about how they use fume cupboards and to adopt good management practices, for example when allocating fume cupboards for different purposes or looking at daily routines for saving energy.

The list of questions opposite gives examples of issues that will need to be considered by the person responsible for fume cupboard management. These should also be communicated to users.

There is often little, if any, training offered in how to use fume cupboards after commissioning. Manufacturers do not normally offer any training on how to operate fume cupboards in an energy-efficient way – again, the lab manager should become involved and ensure that users are suitably trained.

Motivating users to change patterns of usage and begin utilising fume cupboards in a more energy-efficient way is an important part of improving fume cupboard management practices. Generally, there is very low awareness amongst users of how much energy fume cupboards use.

Therefore, as well as training laboratory managers and all support staff in management techniques, users should also be educated in simple good practice measures – for example:

- Making adequate preparations to equipment before the experiment has started. This means that the cupboard does not need to be switched on for so long
- Lowering the sash to the recommended height to maintain a purge volume
- Using time switches to control cupboards or switching them off manually where appropriate

Systems sometimes need to be left running constantly, for example if chemicals are being stored in or beneath the fume cupboard. Where this cannot be avoided try, if possible, to store all chemicals in the same cupboard. Research requirements can also mean that experiments are performed which have to run for some considerable time.

ENERGY-EFFICIENT OPERATION

QUESTIONS YOU SHOULD ASK

What is the fume cupboard used for?

- Use of fume cupboards for storage should be avoided.
- Use of cupboard space below the fume cupboard for storage should also be avoided, but where this is necessary the cupboard should be directly vented to outside rather than through the fume extraction system, in order to avoid having to leave the fume cupboard running for this purpose.

When the fume cupboard is in use

- Lowering the sash on dual fan speed and variable air volume (VAV) fume cupboards saves energy and reduces noise – which can be significant, especially with older models.

Are fume cupboards being left on unnecessarily?

- Users should be told to switch off fume cupboards overnight wherever possible.
- Lab technicians/cleaners/security could be asked to check that such equipment has been turned off.
- Time switches should be used to switch off cupboards when the length of the experiment is known and when the lab is closed.
  Note: It might be necessary to put up a sign to inform others that the cupboard should be left on overnight (for example).

Are face velocities excessive?

- Designation of fume cupboards for particular purposes should be considered so that selected fume cupboards can operate at low face velocities: for instance dispensing/handling of low volatility/low toxicity substances, or weighing operations (where high face velocities can lead to inaccurate measurements).
- Face velocities should be set according to the operations that are likely to be performed in the cupboard.

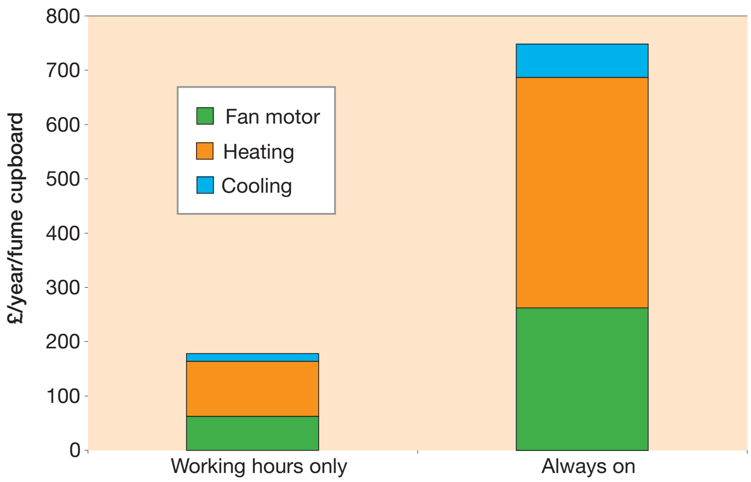
CIBSE Guide B2 states that, generally, good containment can be achieved at face velocities of 0.5m/s, although it may also be achieved at lower face velocities depending on the design of the fume cupboard. Whilst a face velocity of 0.5m/s is appropriate for most purposes, the actual requirement will depend on the application.

What is the working sash height?

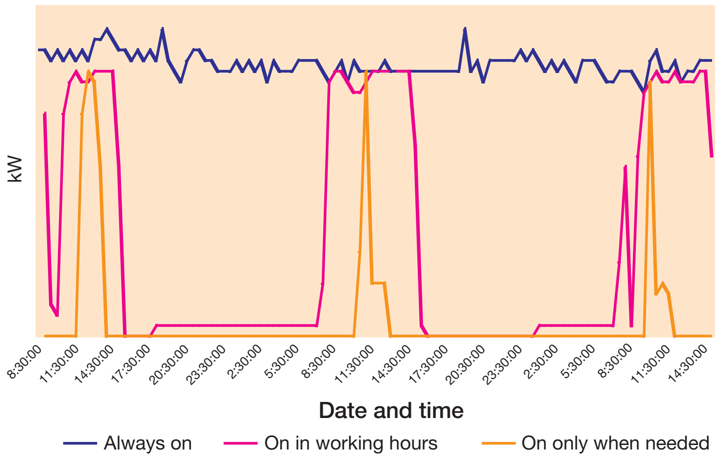
- Users should be made aware that whilst they are working at the fume cupboard, the sash height should be low enough to ensure that face velocities, can be maintained. However, users should ensure that they pull the sash down when they move away from the cupboard – in this way less energy will be needed to condition make-up air as less air will be extracted. It should be noted that closing the sash on a conventional face and bypass cupboard system will have no effect on the volume of air extracted.

ESTIMATING ENERGY COSTS

A standard face and bypass fume cupboard that is left on for 24 hours a day, in a building with both heating and cooling, can cost around £750 a year in energy costs. As illustrated by the bar chart, only about a third of these costs are to run the extract and supply fan motors; the remainder are for heating and cooling the make-up air. In contrast, where the same fume cupboard is switched on only from 9am to 5pm, the costs are under £200 per year.



Fume cupboard running costs



Energy consumption for identical fume cupboards in three different situations

You can see how these costs are broken down even further in the table on page 13, which can also be used to estimate the energy consumption and costs of your own fume cupboards.

The chart below left shows the energy consumption for three identical fume cupboards found in three different situations.

The dark blue line illustrates the energy consumption of a fume cupboard located in a research laboratory. The cupboard is left on continuously to accommodate research requirements of experiments which must be left running overnight. The amount of energy consumed by the cupboard is high, both because of the fan motor consumption and, more significantly, because more energy is required to condition the make-up air. Where this is the case, investigate whether this is absolutely necessary. If it cannot be avoided it may instead be possible to reduce the extract volume.

The pink line illustrates the consumption of a fume cupboard in a teaching lab, which is switched on at the start of the working day and not turned off until everyone goes home, irrespective of whether it is being used for an experiment. The energy consumption of this cupboard is therefore lower than that of the previous case; however, there is the potential to save more energy by switching it off when it is not needed, or reducing the extract volume.

The yellow line illustrates the pattern of use of a cupboard located in a lab where experiments are occasionally carried out that require the use of a fume cupboard. During the times it is not being used, the cupboard is switched off. The amount of energy it consumes is much lower than those in the previous two situations as the fan runs for less time and extracts a great deal less conditioned air. Even in this case, however, it may be that optimum efficiency is not being achieved, and it is worthwhile reviewing sash management practices to see if it is possible to increase efficiency further.

ESTIMATING ENERGY COSTS

		Example	Your details
a	Annual hours of use for your fume cupboard	8736	
b	Your electricity cost £/kWh	0.06	
c	Your heating fuel cost £/kWh	0.015	
Fan motor consumption (extract and make-up air supply)			
d	Motor size (kW) – assume × 2 fans	0.5	
e	Motor: annual energy consumption (kWh) (**a** × **d**)	4668	
f	Annual energy cost (**b** × **e**)	280	
Heating cost			
g	Proportion of the year with heating	7/12	
h	Face velocity (m/s)	0.6	
i	Aperture (m^2)	0.54	
j	Average temperature difference in heating season, assume 10°C	10	
k	Specific heat capacity of air ($kWh/m^3/^oC$)	1.2	1.2
l	Annual heat loss (**a** × **g** × **h** × **i** × **j** × **k**)	19,813	
m	Boiler efficiency, assume	0.7	
n	Annual heating fuel consumption (l/m)	28,305	
o	Annual heating fuel cost (**n** × **c**)	425	
Cooling cost			
p	Proportion of the year cooling	3/12	
q	Face velocity (m/s)	0.6	
r	Aperture (m^2)	0.54	
s	Average temperature difference in cooling season, assume 3°C	3	
t	Specific heat capacity of air ($kWh/m^3/^oC$)	1.2	1.2
u	Annual cooling loss (**a** × **p** × **q** × **r** × **s** × **t**)	2547	
v	Chiller COP, assume	2.5	
w	Annual heating fuel consumption (**u**/**v**)	1019	
x	Annual cooling cost (**w** × **b**)	61	
y	Total costs (**f** + **o** + **x**)	766	
z	Number of fume cupboards	1	
	Total consumption costs (y × z)	**£766**	

This table will help you estimate your own fume cupboard's energy consumption and running costs.

The worked example is for a standard face and bypass cupboard with an aperture of $0.54m^2$, which is left running 24 hours a day.

You should enter your own tariffs for electricity and heating fuel in rows **b** and **c** (it may be that your tariffs are very different to the example – changing to lower tariffs could provide a simple way of lowering energy costs).

Constant values have already been entered where this is appropriate. If you are unable to obtain your own figures for the average temperature differences in the heating and cooling seasons, boiler efficiency and chiller COP, use the values from the example in your calculations to obtain an estimate of energy consumption.

GLOSSARY OF TERMS/HEALTH AND SAFETY

Aperture – the total opening on the front of a fume cupboard through which air is drawn from the lab by the extraction system.

Automatic sash-closing mechanism – infra-red sensors detect operator presence in front of the cupboard and close the sash when the operator is absent.

Backward curved centrifugal fan – these are generally the most efficient types of fans for this application.

Central fan system – multiple fume cupboards share one extract fan.

Constant air volume – the volume of air extracted/supplied remains constant.

Face and bypass cupboard – the fume cupboard found in most laboratories. The sash is smaller than the total aperture of the cupboard – closing the sash opens a grille at the top of the cupboard so that a constant volume of air is extracted regardless of the sash position.

Heat recovery system – a plate is preheated by exhaust air and heats incoming make-up air.

Fresh air bleed system – outside air is drawn into the main extraction duct to supplement the air being extracted from the lab.

Individual fan system – each fume cupboard has its own extract fan.

Re-circulatory filtration – adsorptive material removes harmful substances from the exhaust air, which is then re-circulated around the room.

Single speed fan – extract/supply fans operate at constant volume with ON/OFF control.

Two-speed extract fan – a reduced extract mode is achieved by lowering the sash.

Variable air volume (VAV) – the volume of air extracted/supplied is adjusted via a VAV control system and reduces the volume as the fume cupboard sashes are closed.

Variable speed extract fan – the speed of extract and supply fans varies according to sash height/ number of cupboards in use, etc.

British Standard BS 7258

Some of these recommendations address issues surrounding the use of fume cupboards which may impact on energy efficiency, including, for example:

- The selection of a fume cupboard should be based primarily on the philosophy that the performance should be higher than that demanded by the processes likely to be performed in it
- Excessive extract volume flow rates through the aperture lead to wastage in energy by extracting an unnecessary amount of conditioned air from the laboratory
- The sash should be kept lowered except when actually manipulating equipment, etc
- Details are given for maintenance operations that should be carried out every six and 12 months

COSHH Regulations

- An employer shall not carry on any work which is liable to expose any employees to any substances hazardous to health (see Regulation 2 for a full and complete definition of this term) unless there has been a suitable and sufficient assessment of the risks and of the steps that need to be taken to meet the requirements of COSHH Regulations
- Where it is not reasonably practicable to prevent the exposure of employees to substances hazardous to health, Regulations state that any exposure should be adequately controlled
- Employees are required under Regulation 8(2) to make ‘full and proper use of any control measure ... provided’

CONTACTS AND FURTHER INFORMATION

Other Action Energy publications (formerly available through Energy Efficiency Best Practice programme):

Good Practice Guide
257 Energy efficient mechanical ventilation systems

General Information Report
41 Variable flow control

Recommendations for the use of fume cupboards can be found in **British Standards BS 7258** (Laboratory Fume Cupboards) and **BS 7989** (2001 Specification for re-circulatory filtration fume cupboards), and the **DfES's Building Bulletin 88** – Fume Cupboards in Schools (Revision of Design Note 29).

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Addresses and telephone numbers of the Department's regional offices are available from its website, **www.dfes.gov.uk**

The **Health and Safety Executive's** website, **www.hse.gov.uk** gives contact details for all their divisional offices, as well as many useful links and sources of other information.

Details of regulations and legislation can be accessed online from Her Majesty's Stationery Office, located at **www.hmso.gov.uk**

Items of legislation can be purchased from:
The Stationery Office
PO Box 29
St Crispins House
Duke Street
Norwich
NR3 1PD
Tel: 0870 600 5522
Web: **www.thestationeryoffice.com**

The **Joint Procurement Policy and Strategy Group's** website, **www.jppsg.ac.uk** provides downloads of procurement guidance publications and links to related sites.

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Action Energy – formerly the Energy Efficiency Best Practice programme – provides impartial, authoritative information on energy efficiency techniques and technologies in industry and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the programme are shown opposite.

Visit the website at **www.actionenergy.org.uk**

Call the Action Energy Helpline on **0800 585794**

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy-efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R&D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Introduction to Energy Efficiency: helps new energy managers understand the use and costs of heating, lighting, etc.